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EXPLOITATION OF DISTRIBUTED SOLAR RADIATION DATABASES THROUGH A SMART NETWORK: THE PROJECT SODA

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Abstract – The project SoDa answers the needs of industry and research for information on solar radiation parameters with a satisfactory quality. The methodology is user-driven with a large involvement of users in the project, who will gauge the progresses and achievements. A prototype service will be developed, using Internet technology, that will integrate and efficiently exploit diverse networked information sources to supply value-added information. A multi-disciplinary consortium has been assembled, which gathers companies and researchers with the necessary expertise in solar radiation and information and communication technologies. Customers and potential users are also represented as partners in the consortium via the involvement of commercial private vendors of solar radiation databases and of representatives of large research and development programs. A call is launched to recruit customers to assess the prototype. The project SoDa builds on the expertise gained in previous projects, such as the digital atlases MeteoNorm and European Solar Radiation Atlas, the Web servers Satel-Light and Helioserve, and the Guide of the Chartered Institute of Building Services Engineers of United Kingdom. Access to data and applications will be improved; efforts will be made on interpolation methods and satellite data processing to achieve better quality; emphasis will be put on applications to supply information actually needed by customers, instead of raw data.

1. INTRODUCTION

Information on solar radiation is a critical issue for the use of solar energy. Solar radiation is measured by ground networks of measuring stations, but well-controlled measurements have only been available in a limited number of sites, and since the middle of the 20th century or so. The types of measured data are diverse: sunshine duration, cloudiness, global irradiation, also sometimes its diffuse and direct components, spectral distribution, etc. Ground based measuring networks have been established; but investment and maintenance costs for each site are large. Consequently, national networks often comprise only a few stations, even in Western Europe and Northern America. In other parts of the world, it is scarce. Such data are non-existent for the oceans. The result is that there is a large discrepancy between user request and available information for various purposes detailed below.

Large gains in terms of efficiency, costs, etc. will be attained by engineers, companies, agencies and research institutes if relevant information were more easily available for virtually any geographical location at any time. Information and communication technologies could play a major role in solving this problem. Recent projects have demonstrated the usefulness of image processing techniques for extracting solar radiation information from Earth observation satellite images. Reliable validated routines have been established at some meteorological offices and research institutes. Efforts have been made to collect, store and disseminate solar radiation information. Some achievements have been obtained at international and national levels, through international research programs, some of them funded by the European Commission, others by national meteorological offices or through other initiatives. Several databases are now available, some of them being available through a WWW server.

However these efforts are not sufficient enough. Three major problems have been identified and should be solved to supply the customers with information relevant to their requests:

- Improved access.
- Improved space and time structures. Space and time characteristics of presently available data are unsatisfactory. Interpolation / extrapolation techniques can be employed to gain knowledge at any geographical location and any time, but the present techniques lead to poor quality estimates.
- Improved matching to actual customer needs.

2. THE OBJECTIVES OF THE SODA PROJECT

Several initiatives are operationally producing assessments of the global radiation at ground level for large geographical areas. Probably the most widely known is the ISCCP program (International Satellite Cloud Climatology Project) and its brother, the SRB (Surface Radiation Budget) program which freely provide free maps of the monthly-averaged daily radiation sums for the entire world on a grid of $2.5^\circ \times 2.5^\circ$. Several meteorological offices are offering similar products with a finer geographical grid but covering a narrower area, such as ECMWF (European Centre for Medium range Weather Forecasting), Deutscher WetterDienst, Meteo-France, Swiss Met-Office. These products are commercially available. They are of very great interest to their originators and to specialized researchers in meteorology. However they have limitations for a non-standard 'meteorological user' in several aspects, e. g. geographical coverage, space and time resolution, unsuitable types of data with respect to the various types of request by customers, unsuitable presentation of the information, excessive data volume with respect to the user's computer system (hardware, software). They assume the skills of the end-user lie in handling basic meteorological data rather than processing desired climatic information to address a specific problem. Digital atlases (MeteoNorm 2000; European Solar Radiation Atlas 2000) have been recently created which are more relevant to the field of renewable energies. Presented on CD-ROMs, they comprise a database (maps, time-series of ground measurements, synthetic reference years, geographical information...) and software to exploit it (user interface, data management, result presentation, import-export capabilities...). The software also includes models for the computation of parameters of higher level, such as the diffuse radiation on inclined surfaces, and models for end-users applications, such as the assessment of the quantity of domestic hot water that can be produced at a given location. The European Union funded Satel-Light project offers a database of solar radiation data derived from satellite images, which can be accessed through the WWW (Fontoynt *et al.* 1998; Reise *et al.* 1999). It produces value-added information on inclined surface and sky luminance that is useful in

designing buildings, which efficiently exploit daylighting. The Web server Helioserve offers access to unique databases on the Linke turbidity factor, as well as to a simulation of the clear-sky irradiation (Angles *et al.* 1998, 1999). Though limited to the solar energy domain, these atlases and servers are excellent examples of what can be done to bring to users the information they require starting from basic meteorological measurements.

The project SoDa is based on this considerable previous experience, and will use it as a springboard to answer customer needs by an efficient use of advanced information and communication technologies. More precisely, an integration of information sources of different natures within a smart network will be realized (Figure 1). These sources include databases containing solar radiation parameters and other relevant information (meteorology, geography, terrain elevation, satellite-borne sensor parameters). Several of these databases originate from an advanced processing of remote sensing images. These databases are presently available separately. The information sources will also include application-specific user-oriented numerical models and advanced algorithms. The system will be validated through users trials, and its benefits will be assessed. The project SoDa focuses on several applications: energy-conscious building design and daylighting, and industrial use of renewable energies.

The objectives of the project SoDa are:

- to answer the needs for high quality customer-tailored information on solar radiation
- to integrate diverse sources of information presently available separately within a smart integrating network
- to develop and operate a prototype service, which efficiently exploits this smart network, and which will be used and gauged by selected users
- to increase the quality of the delivered information through improved modeling of time and space structures of the solar radiation, and improved matching to actual customer needs
- to disseminate the achievements of the project, and assess the sustainability of a permanent commercial service

The project consortium gathers all the necessary expertise in the various domains covered by the objectives: solar radiation, databases, networking, image processing, applied mathematics, WWW-based technologies and services, customers needs and satisfaction assessment, information and communications technologies, market assessment and development of business plan for products and services. It comprises companies, research institutes, potential users as well as vendors of existing solar radiation databases.

3. SODA NEEDS YOU!

Customers (international research programs, companies, research institutes) will participate to the project. Their

participation is of large importance in this project. They will help in designing the service, in assessing its value, in assessing the market potentials and in disseminating the outcomes of the project. The project SoDa will welcome your valuable help, which can be on the one hand the expression of your needs, and on the other hand the testing of the prototype (to be available in December 2000) and the expression of its benefits and drawbacks with respect to your present practice.

You may register at www-helioserve.cma.fr/soda.

4. KEY ISSUE # 1: IMPROVING ACCESS TO INFORMATION

A prototype of an intelligent system will be produced for the integration and exploitation of diverse networked information sources. It will create a common access point, which will be implemented as an Internet server. This prototype shall be capable of extracting the most relevant information, according to the user request. The request may be beyond the content of these databases (e.g., APAR, or frequency of clear-sky days). In that case, the system shall include capabilities of synthesizing the relevant answer from the databases using additional knowledge in the form of rules and application-oriented algorithms. The system shall be flexible and not be closed: it shall be capable of integrating other databases and new application-oriented algorithms.

The project will rely upon data exchange protocols and on systems to guide, connect, and transfer data across computer networks, which are already available and reliable. It will design and validate intelligent interface and protocol for data mining for the integration of networked sources, including the geographical databases. The system will be capable of extracting the most relevant information, according to the user need, through a judicious exploitation of both the sources and the application-oriented algorithms. It is foreseen to use many existing tools, which have been developed for the Centre for Earth Observation (CEO) of the European Commission. They are in use within the WWW-based information service INFEO for the CEOS Information Locator System, and for the G7 ENRM (Environment and Natural Resources Management) program. ENRM is an initiative of the G7 group of nations.

A prototype of the intelligent system will be realized as early as December 2000. The software will be based on known reliable systems, e.g. HGS, EWSE, Gelos etc. The system will comprise advanced features including customizable user interface, Java applets and real-time data applications. Data application software will be interfaced to the Web. The HTTP based Geo-Temporal Searching (HGS) technology will be used; it defines a mechanism whereby remote databases can be searched through a single standard HTTP interface. It provides a Service Discovery layer. This allows online retrieval of a hierarchical structure of all databases available for search through HGS.

The project will arrange for the cycle of testing-improvements by providing access of the prototype service to the selected users.

5. KEY ISSUE # 2: IMPROVING KNOWLEDGE ON THE SOLAR RADIATION

Several databases already exist that are to be exploited by SoDa. Though related to solar radiation, these databases are very diverse. The parameters are various: sunshine duration, cloudiness, global irradiation, its diffuse and direct components, spectral distribution, atmospheric turbidity, atmospheric aerosol optical thickness, etc. The support of the information is diverse, too: long time-series are available for a few hundreds of measuring stations (pin-point measurements) while shorter time-series are available for pixels. These pixels have various sizes: from 5 to 250 km; geographical coverages are also various as well as time periods and time samplings. Formats are of course different; some databases are vectorized, others are in raster format. Non-radiation parameters are also of interest in this project, such as terrain elevation and topography (e.g., cities, rivers, coastlines, borders, water bodies). These parameters are useful for map representation to users, and represent also a knowledge that can be exploited for the computation of advanced application-oriented information or the modeling of space and time structures. Daily calibration factors of the satellite sensors will be provided by another database, which can be accessed on the Web. Other databases and resources outside the consortium may be integrated in the prototype service on a voluntary basis.

Apart data, other sources of information are applications. Some can be accessed through the Web. Applications are available to check the quality of solar radiation measurements, to predict the global irradiation for a given atmosphere, or its diffuse component on an inclined surface, the long wave irradiance etc. End-users applications predict the quantity of domestic hot water that can be produced at a given location, or the size of a window for the better exploitation of daylighting in building.

For an efficient exploitation and better services, the databases should be consolidated. Additional information should be incorporated, and the time and space coverage should be increased, taking into account potentials offered by Earth observation satellites.

Additional relevant information will be incorporated in the co-operating resources whenever possible. Air temperature and atmospheric turbidity are such additional parameters. It may be either an existing database that is acquired by the consortium, or may result from extensive computations made using the available information sources or others. Another example is the availability of terrain elevation data which will allow the computation of the slopes, and further the irradiation on slopes.

Several methods have been developed to assess the solar radiation at ground level from images taken by

meteorological satellites. Of particular interest here is the method Heliosat and its several versions, one of the most used methods in the world. These methods perform better than standard interpolation methods applied to ground measurements. The relative error in assessing hourly value of global radiation on a horizontal plane is approx. 50 % (twice the rms.) instead of 70 %. However they have been developed for near real time processing of the data flowing through a receiving station. They are not well adapted for the processing of large archives of satellite images spanning for more than 15 years and taken by several different sensors (the operational Meteosat series range from Meteosat-2 to 7 from 1985 onwards). The version 2 of Heliosat will be developed (Rigollier, Wald 1998; Rigollier *et al.* 2000). It will benefit from the effort recently made to achieve an accurate calibration of the archives of Meteosat images (Lefèvre *et al.* 2000). Such a calibration ensures a constant quality in assessing the solar radiation from 1985 onwards. Besides this major improvement, a slight increase in accuracy is expected. This will be confirmed by the comparison of time-series of satellite-derived assessments and of measurements made at several tens of meteorological sites. The Heliosat version 2 should also be easier to implement and to operate.

The time and space coverage of databases will be completed by using satellite data whenever possible. Because of the large diversity in space and time coverage and sampling of the available databases, it is not possible to process all the available archives of satellite data in order to fill all the gaps in space and time. Accordingly, a trade-off will be found. It is foreseen that several sets of images will be processed with various coverage and sampling rate in space and time. The geographical coverage will focus on Europe and adjacent regions. The image processing techniques presently used will be improved to increase the quality of the satellite-derived information. Whenever possible, fusion of ground based measurements (contained in the databases) and satellite-derived assessments will be performed by means of geostatistics or similar techniques. It has proved very fruitful in providing high-quality information for solar radiation (Beyer *et al.* 1997).

6. KEY ISSUE # 3: IMPROVING MATCHING TO ACTUAL CUSTOMER NEEDS

Advanced exploitation of the databases content will be developed. Its objective is to improve the quality, taken in a broad sense, of the delivered information. It takes into account the expression of the user needs. Efforts will be put on the assessment of parameters in any geographical location at any time, and on the provision of advanced parameters and application-oriented information.

Advanced and original interpolation / extrapolation schemes will be developed that take into account the terrain elevation profile, orographic features and all geographical features of relevance for solar radiation

(e.g., large water bodies) and their known consequences (e.g., bands of clouds along the coastlines of the Adriatic sea), the local climate, and the space and time local characteristics of the solar radiation. Artificial intelligence will be called upon for efficient schemes that are adapted to local conditions. In some aspects, these schemes may be seen as data fusion processes that operate simultaneously at several semantic levels. Because of the complexity of the environmental processes, the schemes will necessarily perform at various space and time scales. The multi-resolution analysis and possibly the wavelet transform theory will be used to describe the information and its change in space and time.

The purpose of these schemes is to create information when missing from that existing. Even if large databases covering large periods of time at high-frequency and large geographical areas at high sampling rate will be created, it will not be enough to meet all the users needs. Thus interpolation schemes are necessary to fill gaps. These schemes will also deal with highly variable geophysical parameters such as air temperature. Finally another original feature of this work is the consideration of extrapolation / interpolation in both the frequency - wavenumber and time - space domains.

Advanced parameters and user-oriented applications information will be derived from the databases content to precisely answer the customer request. Advanced parameters denote parameters that can be obtained by the application of a fairly simple algorithm or scheme on the databases and other resources. User-oriented applications denote information that results by performing a sophisticated calculation using the SoDa resources as inputs. It is intended that all the algorithms to retrieve advanced parameters will be part of the SoDa service, while some user-oriented applications may be too complex to be fully integrated.

Of particular interest is the solar radiation available on slopes, while measurements are always made on horizontal surfaces. Algorithms will be developed to provide such information taking into account the digital elevation model and the optical properties of the atmosphere. Algorithms for assessing the impact of obstructions around specific sites on irradiation will be developed and tested. Statistical tools will be available, as well as simulation tools of typical daily profiles of values starting from monthly averages or from daily sums. Such profiles are useful as inputs to models in various domains. It is intended to develop the following algorithms:

- ◆ clear-sky irradiation and its direct and diffuse components
- ◆ splitting global irradiation into direct and diffuse components
- ◆ longwave irradiation
- ◆ illuminance
- ◆ spectral distribution of the irradiation

- ♦ astronomical parameters (eccentricity, time equation, solar declination, daylength, sunrise and sunset time, solar angles, etc.)

This list is not limited and will evolve with the users requirements and the available resources in and outside the consortium. As much as possible, existing algorithms of satisfactory quality will be adopted. Further improvements may be brought. In particular, an effort will be made to derive information related to the UV radiation from the SoDa resources. Such an algorithm is not available presently.

As far as user-oriented applications are concerned, the project SoDa will focus on a few of them. The solar radiation is a key force in vegetation. It is a key parameter in the primary production and biomass, and as such, users in this domain are very keen at a better knowledge. The project SoDa will concentrate on the assessment of the fraction of the solar radiation that is available for the photosynthesis (including slope effects). Existing algorithms will be adapted and possibly improved for their integration in SoDa, and will deliver this fraction for virtually any place in the world.

Other applications of interest to the project SoDa are those related to the engineering of solar systems, and to buildings and daylighting. Many user-oriented application tools already exist in these domains. They will be integrated into the SoDa service. Among them are those present in the commercial CD-ROMs (MeteoNorm, ESRA), in the server of the Satel-Light project for daylighting in buildings, or in the Guide of the Chartered Institute of Building Services Engineers (U.K.). These documents and services will constitute the baseline for that task. It may be not possible to integrate all of them in the SoDa service.

7. PERSPECTIVES

The project SoDa is a real breakthrough. It represents a significant step forward beyond the current state of the art and includes substantial original work. The main innovations of SoDa are to offer a smart access to diverse networked sources of information, and to supply the customers with information of high quality. High quality means an improved matching to actual customer needs: the supplied information is relevant to the different user needs and not just raw observed data. It also means an improved access. Finally it means improved time-space coverage and improved time-space sampling.

The project SoDa includes original work on the assessment of the usefulness of satellite-derived information in solar radiation and of its dissemination. Satellite derived radiation data provides information about both direct beam and diffuse radiation. This is very important considering the relatively small number of ground sites in the world measuring diffuse radiation.

Since the project SoDa will be based upon available experience, the resulting prototype will be recognized by, and integrated into larger worldwide networks of

environmental databases. The tools and other findings of this project may be exploited for the integration of databases containing parameters related to another theme (environmental process or others) with different supports, formats, time and space coverage, sampling and period.

Besides these technical innovations, a number of benefits are expected some of which are socio-economic innovations. Because the prototype service is directed towards users and will provide easy access to sophisticated user oriented information on solar radiation, it will lead to:

- an excellent means for verification of already existing solar radiation data, and their extension (temporal and spatial), also for climatological studies using numerical models where the solar radiation is input,
- an improvement in tools where advanced solar radiation information is input,
- more generally, a better efficiency in scientific research and development in all areas where solar radiation makes significant impacts,
- a better understanding by industry of the impact of climate on their product in the market-place and on their production processes, leading to improvements in their economic and social performance, cost-savings design of industrial systems,
- an improved understanding of the significant role of solar radiation in the city of future, and the place of renewables in future urban development,
- improved management of natural environment, biodiversity and urban resources drawn from countryside environment like water,
- better prediction of some natural hazards like photochemical air pollution, snow melt hazards, state of the ground in relation to water run off, low summer river flows due to evapo-transpiration,
- a key tool for the improved management of all biomass systems including agriculture,
- improved citizen awareness of the role of solar radiation as the key force in global sustainability.

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Figure 1. A schematic view of the SoDa prototype

